

# Frequency in the input affects perception of phonological contrasts for native speakers

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## Abstract

We present an analysis of phoneme frequency in the Wubuy lexicon and in spoken texts, highlighting striking differences in the relative frequency of occurrence of the phonemes of Wubuy. We apply this analysis to previous work showing curious—and theoretically very interesting—differences in native Wubuy speakers' ability to discriminate their native coronal stop contrasts [1]. Our analysis suggests that acoustic differentiation cannot account for the patterns observed and that relative frequency of occurrence systematically influences the discrimination accuracy of native speakers and indicates that input frequency likely accounts for some of the differences in discrimination accuracy observed.

**Index Terms:** Phoneme frequency, perception, coronals.

## 1. Introduction

Previous research has shown that native stop discrimination accuracy in Wubuy varies systematically according to the stop contrast in question [1]. This pattern of perceptual behaviour in native speakers has not been widely documented: native segmental speech perception is usually assumed to be near perfect, in particular for consonants. For this reason, native speakers' perception is typically only presented as a control condition in speech perception experiments. In what follows, we present the results of an analysis of the frequency of consonants in the input in Wubuy, and interpret the previous perceptual findings in the light of this novel approach.

## 2. Wubuy phonology

Wubuy is an endangered Indigenous Australian language spoken in south-eastern Arnhem Land, around the southern part of Blue Mud Bay. It is the first language for adults over the age of around 55 in the community of Numbulwar, NT, as well as a first or second language for many adults in neighbouring Groote Eylandt. Children are no longer acquiring Wubuy as a first language, though all children in the community are exposed to some Wubuy through the local language revitalisation efforts at the school. There are currently perhaps 60 fluent first language speakers.

The consonantal inventory of coronals in Wubuy is presented in Table 1 (there are also labial stop /p/ and nasal /m/, and dorso-velar stop /k/, nasal /ŋ/, and glide /w/, not shown here). The phonology of Wubuy resembles the neighbouring Yolngu languages in having a cross-linguistically rare four-way coronal place distinction among the stops /t̪, t, t̺, t̺̺/. We follow [2] in using the 'curly-tailed' coronal stop symbol 't̺', indicating alveopalatal articulation, rather than the common IPA choice 'c', since the latter fails to indicate the essential articulatory and acoustic coherence of

the coronal stop series in Australian languages, and in particular fails to correctly capture the location and nature of the constriction for the most posterior stop in the series.

Table 1. *The phonemic coronal inventory of Wubuy.*

	Lamino-dental	Apico-alveolar	Apico-retroflex	Lamino-alveopalatal
Stop	t̺	t	t̺̺	t̺̺̺
Nasal	(ɲ)	n	ɲ	ɲ̺̺
Lateral	l̺	l	l̺̺	
Tap/trill		r		
Approx.			ɻ	j

According to [3], the four-way coronal series is contrastive both word-medially and word-initially, though it is claimed that the apical contrast (i.e., /t̺-/t̺̺/) is difficult to perceive in the absence of a preceding vowel in Wubuy. Similarly, [4] suggests that, in a number of burst-related measures, that /t̺, t, t̺̺, t̺̺̺/ are well-differentiated in medial position, and that /t̺, t/ and /t̺̺, t̺̺̺/ are similarly well-differentiated in initial position, while /t, t̺̺̺/ (just as in [3]) is not differentiated initially.

A survey of the phonotactics of Australian languages presented in [5] identifies just 10 languages (from 116) with a word-initial apical contrast, many of them now extinct or moribund. As can also be seen from Table 1, Wubuy also has a four-way coronal contrast in nasals (though the dental nasal /ɲ/ is only found in loanwords), and a three-way contrast in laterals, where it lacks the lamino-alveopalatal phoneme.

## 3. Native perception of Wubuy coronals

[1] has demonstrated that the discrimination of Wubuy coronal stop contrasts by native speakers is not perfect (see Fig. 1).

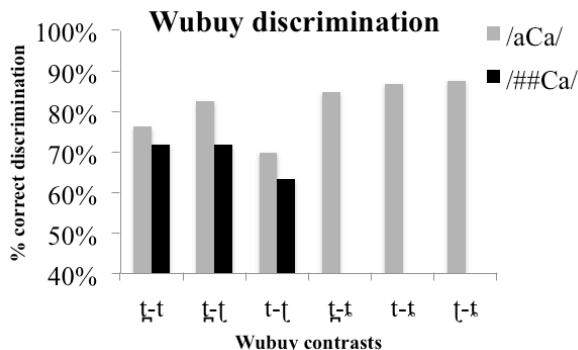


Figure 1. *Discrimination of coronal stop contrasts by native speakers of Wubuy in two conditions, from [1].*

Specifically, the results showed that, while all contrasts involving the lamino-alveopalatal stop /t/ are discriminated with ease (85-88% correct), all other coronal stop contrasts (those involving /ɬ, t, t/) present difficulties for native listeners.<sup>1</sup> However, even within contrasts involving /ɬ, t, t/, there are differences in discrimination accuracy, such that the apical contrast /t-t/ is more difficult to discriminate than the other two contrasts /t-t/ and /ɬ-t/. This is despite the fact that, as reported in [4] and [6], the acoustic differentiation of the dental /t/ from the alveolar stop /t/ is on par with the apicals (/t-t/), particularly in initial position. Amongst plausible explanations for these differences in discriminability are the great acoustic differentiation of the lamino-alveopalatal from the other three stops [7], but this does not explain the differences in discriminability between /t-t/, /t-t/ and /ɬ-t/. We suggest that additional explanations for the observed differences might be found in an analysis of the relative frequency of occurrence of these stops in the native language input of the Wubuy speakers.

#### 4. The input in Wubuy

In order to understand the characteristics of the input to native speakers, we examined (1) the distribution frequencies of phonemes in the lexicon of Wubuy and, (2) the frequency characteristics of phonemes in natural text. Wubuy is well-documented in a three-volume work encompassing a large collection of transcribed oral texts [8], an extensive dictionary [9], and a grammar [3]. Since sources of transcribed conversational Wubuy are limited, we examined the texts, recorded in the 1970s from native speakers who had grown up in a largely traditional lifestyle. Before discussing the texts, we first examine the nature of the lexicon, which is important for understanding the somewhat unusual phonotactics of Wubuy in general.

##### 4.1. Phoneme frequency in the dictionary

A tabulation of the entries in [9] shows that it contains 4429 words with a total of 18,179 consonants. Of these, 498 are retroflex stops /ɬ/, 430 are alveolar stops /t/. Although the four-way coronal stop contrast is found word-initially, an examination of the frequency of initial consonants in the lexicon reveals that the phonemes involved are distributed unevenly, as shown in Table 2. Overwhelmingly, the most frequent word-initial consonant is /w/, accounting for over 33% of the total lexicon. The phonemes of interest to our study are the coronal stops. Here, there is a clear distinction in relative frequency between, on the one hand, apicals and laminals, and on the other, between the retroflex and the alveolar. The laminal stops /ɬ/ and /t/ are twice as frequent word-initially as the next most common coronal stop, the retroflex. The retroflex is more than three times as frequent as the alveolar, which is among the set of five phonemes which each constitute less than 1% of the word-initial segments (the others are /ŋ, ŋ, r, l/ in decreasing frequency). Despite the low frequency of initial /t/ in the lexicon, several words in this category are frequent in naturally occurring speech, including /tan/ 'guts', the verbs /ta-/ 'defecate' and /ta-/ 'copulate with', and the adjective /tuma/ 'black'. Words of these syntactic categories also occur in the class of /t/-initial roots, for

example /tʉkut/ 'fodder', /tʉparɬa-/ 'to cut down the middle', and /tʉku/ 'raw'.

In order to further assess the relative frequency of the coronal stops (and consonants with a retroflex/dental/alveolar place of articulation irrespective of manner of articulation) in speech, we analysed the distribution of consonants in 8% of the spoken Wubuy texts [8].

Table 2. *Frequencies of phonemes in all entries in the Wubuy dictionary [9].*

		Initial N	%	Total N	%
Stops	p	250	5.64	1364	7.50
	ɬ	71	1.60	498	2.74
	ɬ	114	2.57	544	2.99
	t	20	0.45	430	2.37
	t	126	2.84	1123	6.18
	k	233	5.26	2043	11.2
Nasals	m	566	12.78	1567	8.62
	n	113	2.55	709	3.90
	ŋ	0		5	0.03
	ŋ	15	0.34	388	2.13
	ɲ	16	0.36	463	2.55
Laterals	ŋ	289	6.53	1297	7.13
	l	5	0.11	1167	6.42
	ɬ	343	7.74	601	3.31
Approx.	ɬ	96	2.17	764	4.20
	r	8	0.18	1767	9.72
	ɬ	225	5.08	955	5.25
	w	1474	33.28	1535	8.44
Total	j	465	10.50	959	5.28
		4429		18179	

##### 4.2. Phoneme frequency in the texts

We analysed approximately 2200 words (see below for a discussion of the definition of 'word') from six texts by two male speakers recorded in the early 1970s (see Table 3). Informally, we can observe that a large proportion (23%) of words begin in the alveolar nasal /n/, which makes up only 2.5% of word-initial segments in the lexicon: a difference in order of magnitude. In contrast to /n/, all other coronals are rare word-initially. The two laminal nasals occur not at all, and the retroflex nasal occurs less than 1% of the time (3 out of 1651 initial consonants). The coronal stops are all under-represented in initial position: none occurs more than 2% of the time; the same is true of laterals. Stops in general, however, are all relatively rare in initial position. Apart from the alveolar nasal, the most common word-initial segments are the velar nasal /ŋ/ (14%), the labial nasal /m/ (12%), and the glides /w/ (28%) and /j/ (9.45%). Together, these five segments account for 90% of word-initial consonants in the texts. The 'words' we have referred to here are 'syntactic words': words as defined by the syntactic criterion of movement and isolability in citation. Wubuy is a prefixing language, and many syntactic words begin in prefixes. These realise the grammatical categories of gender and referentiality in nouns [10] and agreement in verbs. It is worth noting that these prefixes use a limited set of initial consonants: /n/, /w/,

<sup>1</sup> We propose the label [—sharp] for this group of coronals; see [2] for discussion of its relevance to the coronal class in Australian languages.

/j/, /ŋ/ and /m/. For example, of the 10 gender prefix forms, the only consonants that occur are these five. As we have shown above, these are exactly the 5 segments that account for 90% of word-initial consonants in the texts analysed here. The verb agreement prefixes represent an even more delimited set. Overwhelmingly, agreement prefixes begin in one of /n/, /ŋ/ or /w/, a subset of the consonants that gender prefixes can begin with. Other consonants are quite rare. Importantly, 'syntactic words' represent the prosodic form closest to the stimuli used in our studies, in that these were prosodic isolation forms.

Table 3. *Frequencies of phonemes in 6 texts in [8]*

		Initial N	%	Total N	%
Stops	p	64	3.88	561	6.21
	t	11	0.67	118	1.31
	ʈ	11	0.67	130	1.44
	t	31	1.88	175	1.94
	ʈ	24	1.45	464	5.13
	k	40	2.42	835	9.24
Nasals	m	196	11.87	808	8.94
	n	382	<b>23.14</b>	1195	13.22
	ɲ	0		0	
	ŋ	3	0.18	51	0.56
	ɲ	0		335	3.71
	ŋ	229	13.87	1086	12.01
Laterals	l	8	0.48	348	3.85
	ɭ	16	0.97	134	1.48
	ɭ	2	0.12	135	1.49
Approx.	r	0		766	8.47
	ɻ	15	0.91	269	2.98
	w	463	28.04	915	10.12
	j	156	9.45	716	7.92
Total				9041	6.21

Because syntactic words frequently begin in one of the small number of consonants identified above, we also investigated the properties of verb roots in the entire text corpus published in [8]. Every clause in Wubuy must have a predicate, usually a verb but sometimes an adjective or nominal. All predicates in the text corpus are preceded by the equals sign '=' making extraction from the digital version of the corpus relatively simple using regular expressions. In Table 4, we present the frequencies of root initial segments in the corpus (a total of 4261 predicates). There are significant differences between the segmental possibilities in root-initial position compared to those found most frequently at the beginning of syntactic words. The data presented in Table 4 is a function not just of the greater range of consonants found root-initially but also of the most frequently occurring verbs found in text (verbs such as /ŋu-/ 'eat', /na-/ 'see', /ja-/ 'go', /ʈa-/ 'stand', and /pura-/ 'sit' are highly represented, as they are in natural conversational speech in Wubuy). Unlike prefixes, verb roots commonly carry the major stress accents in phrases [11]. Roots, particularly nominal roots, can occur unprefixes with some regularity. Nouns in citation, or in focus, typically lack an overt prefix [3], [10]. The possibilities for verbs to occur without an overt prefix are much more limited: only when both arguments of a transitive verb are non-human; we

counted a total of 30 instances of this kind in [8], a volume of over 500 pages of Wubuy texts. Intransitive verbs, and non-verbal predicates such as adjectives and nouns, never lack an overt agreement prefix.

Table 4. *Frequencies of consonant phonemes in verb-initial position in all Wubuy recorded texts [8].*

	Verb Initial	%
Stops	p	344 8.68
	t	33 0.83
	ʈ	67 1.69
	t	67 1.69
	ʈ	123 3.10
	k	125 3.15
Nasals	m	321 8.10
	n	438 <b>11.05</b>
	ɲ	0
	ŋ	0
	ɲ	1 0.03
	ŋ	292 7.37
Laterals	l	2 0.05
	ɭ	295 7.44
	ɭ	69 1.74
Approx.	r	0
	ɻ	322 8.12
	w	520 13.12
	j	908 22.91
Elision	334	8.43
Total	4261	

Comparison of POA frequency of stops, nasals and laterals in word initial, verb initial and all word positions

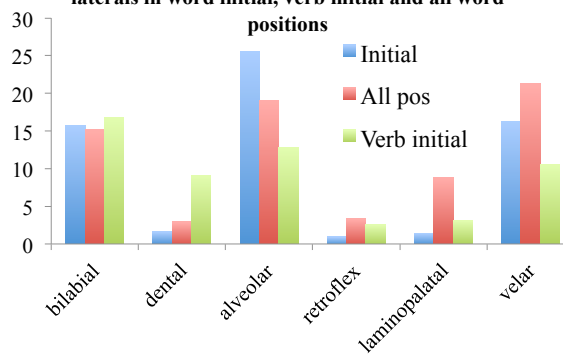


Figure 2. *Distribution of the different places of articulation in the Wubuy texts.*

There are similarities in the distribution of individual segments found most frequently in the root-initial position, compared to the distribution across words. Across words, the most frequent consonants are the labial /m/, alveolar /n/ and velar /ŋ/ nasals (9%, 13%, 12%), the approximants /r/ (8%), /w/ (10%), and /j/ (8%), and lastly the stops /p/ (6%), /k/ (9%), and t (5%). In the root-initial position, we also find the nasals /m, ŋ/ (7-8%) and /n/ (11%), also the approximants /j/ (23%), /w/ (13%) (but not /r/), and the peripheral and lamino-

alveopalatal stops /p/ (9%), /k/ and /t/ (both 3%). These patterns are typical of Australian languages in general; see [5] for an extensive phonotactic survey of this kind.

However, when we compare the distribution of place contrasts (by stops, nasals and laterals) across these three contexts we find significant differences in the frequency of coronals initially in verb roots compared to their occurrence word-initially, and generally across words (see Figure 2). The dental consonants which are under-represented in both word-initial and cross-word contexts have a frequency similar to that of the other major places of articulation—labial, alveolar and velar—in the root-initial position of verbs. The lamino-alveopalatals, which among coronals have the second highest representation across words (after alveolars), have a low frequency verb root-initially, similar to retroflexes. Significantly, the retroflex consonants are under-represented in *all* contexts: word-initial, root-initial, and across words, failing to obtain 5% in any of these contexts.

In sum, what we find from investigating the frequencies of both individual consonant segments and feature contrasts contributed by all contrastive manners of articulation (stops, nasals, and laterals) is that certain contrasts likely suffer a significant frequency disadvantage in naturally occurring speech. This is particularly true of the retroflex consonants, which never exceed a 3% frequency of occurrence in any context. The dentals, while under-represented in words generally, form a significant proportion of root-initial segments: arguably highly salient for the purposes of word retrieval when listeners are unable to identify a word until the root-initial segment, which will in most cases be the first segment that allows word identification [12].

## 5. Frequency affects perception

We have suggested above that relative frequency of a given phoneme in the input affects native speakers' abilities to discriminate those phonemes in their native language. An application of the frequency analyses above to the native Wubuy listeners' discrimination accuracy reported in [1] provides new insights into the accuracy limitations of native speech perception and the contribution of input to such observed limitations. We argue that, while there are differences in the degree of acoustic differentiation between these stops, the differences in discrimination performance between contrasts that contain the lamino-alveopalatal /k/ (on the one hand) and, indeed, between those involving the other coronal stops may not be explained solely by the very subtle acoustic differentiation of the three [—sharp] consonants. For example, predictions based on acoustic analysis alone would suggest that any contrast involving the dental would be reasonably well-discriminated in both medial and initial position, while the /t t/ contrast would be well-discriminated in medial position but at near-chance in initial position.

We argue that the analysis reported above suggests that frequency in the input to native speakers may affect the robustness of phonemic contrasts, resulting in native contrasts which are demonstrably harder for native speakers to discriminate than others. The three coronal stops discussed here (/k t t/) exhibit clear differences in input frequency—both in (1) their overall distribution in the lexicon, as well as in (2) their relative frequency in input, and also (3) in their occurrence in particularly salient positions in words.

In conclusion, the results from our phoneme frequency analysis, applied to [1], suggest that the characteristics of the language input play an important role in determining which

contrasts are more difficult to discriminate when there is no lexical information available (i.e., in a perceptual testing situation). While the listeners were able to discriminate /k t/ (and to some extent /t t/) when these contrasts were presented word-initially, contrasts with /t/ in particular appear to be difficult for native listeners. We argue this is due to the rarity of the retroflex stop in word- and verb stem-initial position in Wubuy. The other stop which is rare word-initially (though not root-initially) is the lamino-dental /k/. It was exactly this contrast pair /k t/ which showed the only significant difference in discriminability according to context: word-initially it is discriminated significantly more poorly than in word-medial position [1], despite the fact that this is acoustically the most well-differentiated contrast pair in this environment [4]. We take this result to confirm our proposal that the characteristics of the input shapes listeners' expectations of the likelihood of a given phoneme occurring in a particular position.

## 6. Conclusion

Our analysis of the distributional characteristics of coronal phonemes in Wubuy demonstrates that such information can provide a valuable insight into the performance of native speakers in perception studies. While the gross differences between the acoustics and articulation of the alveopalatal vs the other three coronal stops can provide a certain amount of explanation for the differences in perceptual performance, the smaller differences within the three [—sharp] stops are unexplained by these factors. However, their discriminability, both pairwise, and according to different prosodic contexts, can be explicated with reference to their asymmetrical distributions in the input.

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